The ESE Technology Strategy Team

By Barbara Wilson, Director
Center for Space Microelectronics Technology
April 28, 1999

Technology Products for Earth Science

- CSMT Program Overview
- Sensors and Instruments
  - Microwave and Millimeter Wave Receivers
  - Long Wavelength IR Arrays
  - Lithographic Optics
  - Microweather Station
- Active Sensing
  - Miniature Diode Laser Instruments
  - Advanced Radar Systems
- Micro Systems
  - On-Chip spacecraft systems
  - Distributed Sensor Webs
  - Microspacecraft
- Advanced Computing
  - Remote Exploration and Experimentation Project
  - High Performance IT Integration
  - Intelligent Synthesis Environment (ISE)

Earth Science Enterprise Global Vision

- A comprehensive climate model of the Earth, including the interactive effects of atmosphere, oceans, ice, land cover, ocean biomass, and solar illumination, and the supporting coordinated measurements, that together can be used to understand and predict the state of the climate on global and regional scales.

- A full understanding of the chemical composition and the chemical and transport processes in the Earth's atmosphere on the regional to global scale, and the supporting measurements that can be used to detect and monitor changes, determine causes, and predict trends that impact life on Earth.

- A comprehensive understanding of Earth's land and ocean ecosystems, and how these systems respond to and influence atmospheric constituents and climate variability, such that ecosystem health can be monitored and predicted on regional and global scales.

- A comprehensive model of Earth's interior structure and dynamics, and the supporting global measurements, that together can be used to predict future global and local impacts, and respond to the effects of natural disasters.

Program Philosophy and Objectives

- Work closely with the scientific community/NASA Strategic Plan to identify detector and instrument needs of future space missions.
- Develop innovative High-Risk/High Payoff Devices and Detectors for NASA Space Missions not available from industry nor likely to be developed elsewhere.
- Conduct research and advanced development jointly with Academia and Industry. Look for co-funding from DARPA, DOD and other agencies.
- Transfer technology to NASA projects for co-funding to ensure successful insertion.

FY 99 Program External Collaborators

Caltech, UC Berkeley, Michigan, Stanford, MIT, UCLA, University of Mass, UC Santa Barbara, Iowa State University, University of Houston, etc.

Lockhead Martin, Honeywell, TRW, QED, David Sarnoff Research Center, Bell Labs

MIT Lincoln Lab, Sandia National Lab, Lawrence Livermore, Lawrence Berkeley Laboratory

1999 CSMT Resources

NASA: Code S, Y*, M and R

DoD: BMDO, DARPA, Navy, AF, Army

Others: NRO, JPL–DRDF, Caltech Presidents Fund, NASA Centers – LeRC, Marshall, GSFC

Total ‘99 Funding ~ $39M

* RTOP, EOS, IIP

1999 NASA/ESE Instrument Incubator Program Tasks with JPL PIs

PI NAME	CO-INVESTIGATORS	PARTNERS Name	PARTNERS Type	CATEGORY	TITLE
Aumann, H.H.	Thomas Kampe, Thomas Pagano, Randolph Pollock	Ball	I	IR Sounder	The Spaceborne Infrared Atmospheric Sounder (SIRAS) for EOS Follow-On Missions
Diner, D.J.	Thomas S. Pagano			Multi-Angle Vis/SWIR Sounder	Miniaturized, Advanced MISR Camera for EOS Follow-on Missions
Fu, Lee	Ernesto Rodriguez			Radar Altimeter	Advanced Altimeter for Ocean Studies
Gaier, T.	Sander Weinreb	U Mass	U	Millimeter-Wave Sounder	Millimeter-Wave MMIC Atmospheric Temperature and Humidity Sensors
Im, E.	S. Durden, A. Berkun, Z. Haddad, J. Huang, W. Edelstein, Eric A. Smith	FL State	U	Rain Radar	A Second-Generation Precipitation Radar (PR-2) Adaptable for Multi-Mission and Multi-Orbit Applications
Lambrigtsen, B.	A. L. Riley			MMIC Microwave Sounder	High Altitude MMIC Sounding Radiometer (HAMSR) on a Remotely-Piloted Aircraft
Lichten, S.	L. Young, J. LaBrecque, G. Hajj, C. Zuffada, T. Meehan, J. Srinivasan, S. Lowe			Reflection GPS	GOALS: GPS-Based Oceanographic and Atmospheric Low-Earth Orbiting Sensor
Njoku, E.	R. Freeland, W.J. Wilson, S. H. Yueh, Thomas Campbell, Y. Rahmat-Samii	UCLA LaRC	U N	Microwave Ground Imager	Study of a Spaceborne Microwave Instrument for High Resolution Remote Sensing of the Earth Surface Using a Large-Aperture Mesh Antenna
Walter, S.J.	K.Franklin Evans	U CO	U	Submillimeter Ice Radiometer	Submillimeter-wave Cloud Ice Radiometer

Sensors and Instruments

Millimeter- and Submillimeter-Wave Technology Products for ESE

-
  - Stratospheric Photochemistry (e.g., Ozone Depletion)
  - Tropospheric Chemistry
    - Water Content/Phase of Upper Troposhere
- Thermodynamic State – Temperature and Humidity Sounding
- Cloud-Radiation Feedback in the Climate System
- Impact of Aerosols on Cloud Radiative Properties

Candidate Missions	Instruments	JPL Technology Products
•Adv. Microwave Sounder (OP-1)	Adv. Tech. µWave Sounder	MMIC Low-Noise Amplifiers (LNA's)
•Geostationary Sounder (OP-4)	Synthetic Aperture µWave Sounder	MMIC LNA's Digital Correlators
•Statospheric Composition (EOS-CHEM; EOS-7)	MLS, Array MLS	Low-Noise Submm Mixers/Arrays TeraHertz Mixers and LO's MMIC LNA'S HEMT Amplifiers
•Cloud-Radiation Feedback (EX-3)	Cloud-Ice Radiometer Cloud Radar (W-band)	TeraHertz Mixers and LO's Mixer Diode Arrays

InP Low Noise Amplifier Development

:

- OP-1 Advanced Technology Microwave Sounder
- Crosstrack Sounder, cloud clearing for IR Instrument

:

- EOS-7 Array Microwave Limb Sounder
- Atmospheric Chemistry Mission

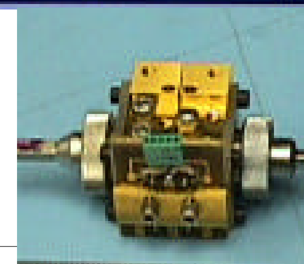
- OP-4 Imaging sounder
- EO-3 Mission concept

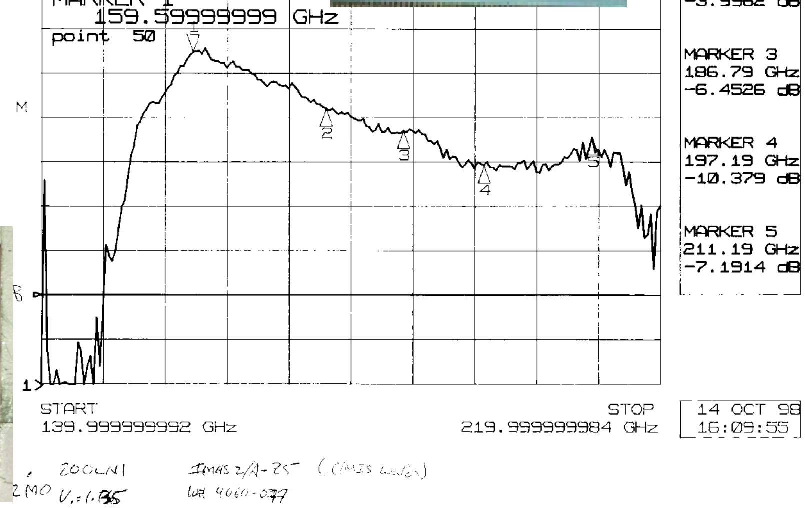
InP Low Noise Amplifier Development

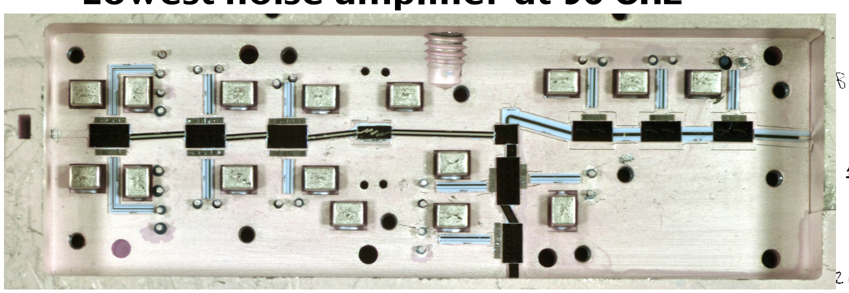
- Upper atmospheric chemistry
- Tropo/meso-spheric temperature, pressure & humidity for thermodynamic state, cloud clearing and storm-tracking
- Cloud radar

- Low noise InP HEMT MMIC amplifiers and receivers from 60-240 GHz with TRW

- Integrated receivers at 60 and 118 GHz
- First low noise amplifiers up to 215 GHz
- Lowest noise amplifier at 90 GHz



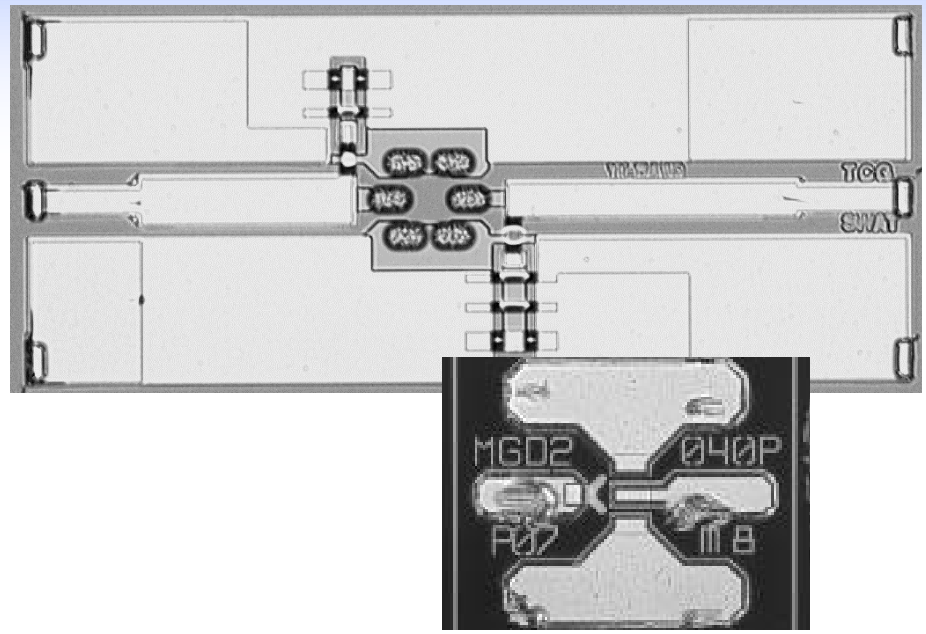




Bump-Bonded HEMT Amplifiers

- Bump-bonded amplifiers
- Amplifiers for cryogenic low-noise receivers to >100 GHz and power amplifiers for local oscillators up to 200 GHz. For SEU and astrophysics missions
- Using the best available discrete HEMT devices, match MMIC amplifier performance for a fraction of the cost and delay

  - TRL 2 (99)



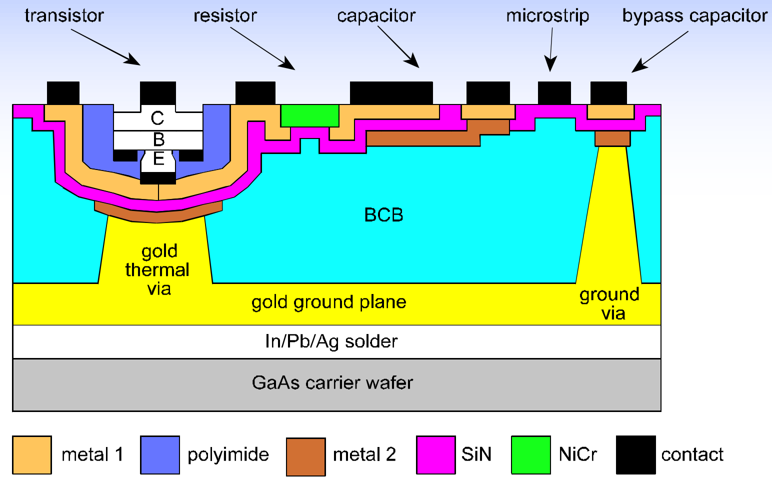
Future CMB missions, ARISE, SAILS, AMLS, EPE EX-3, OP-3 and OP-4

- R.P. Smith, L.Samoska, T.Gaier, P. Pinsukanjana
- (818)354-4424, r.peter.smith@jpl.nasa.gov

Transferred-Substrate HBT Amplifiers

- Monolithic HBT amplifiers
- Extend amplifier technology to terahertz frequencies, particularly for power applications. Will enable high-power local oscillators at THz frequencies
- Combine deep-submicron lithography, advanced materials, and reduced feedback capacitance by reducing collector size.
  - TRL 2 (99)
  - Have just produced world's first transistors with fmax>1 THz

Integrated Circuit Technology



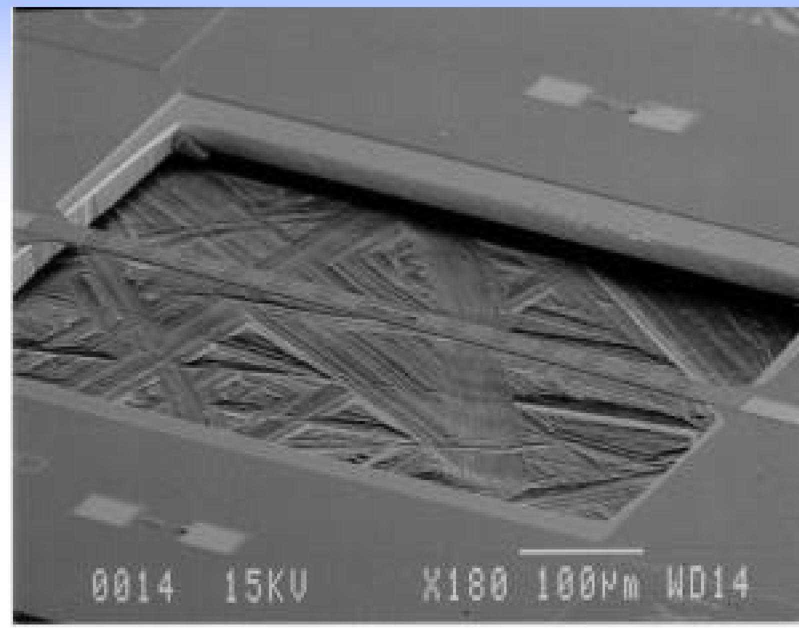
• very high HBT bandwidths, low interconnect capacitance, low ground-return inductance, low thermal resistance

ESE EX-3, planetary interferometry at THz.
SSE ARISE

- R.Peter Smith, Suzanne Martin (JPL)
- Mark Rodwell, Michelle Lee, Dino Mensa (UCSB)
- (818) 354-4424, r.peter.smith@jpl.nasa.gov

GaAs Membrane Diode Technology for THz Sensors

- GaAs Membrane Diode (MOMED) sensor components
- Extends planar MMIC diode technology to THz frequencies for forming downconverters, sources, detectors, arrays, planar antennas
- Utilizes simple wafer level GaAs MEMS processing and e-beam device lithography to realize submillimeter wave components
  - TRL 2 (99)
  - First realized devices delivered for flight in 2000 (2.5 THz mixer)



Earth: EOS-MLS, AMLS, Cloud Ice
Astrophysics: FIRST; Planets: VESPER, MIRO
•Co-funding from customers: Both MLS & FIRS
currently supporting development/flight qua
cation activities.

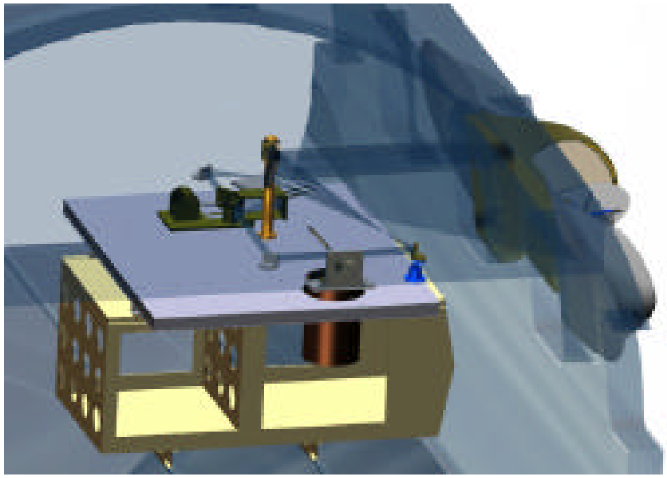
•Peter H. Siegel, R.P. Smith, M. Gaidis, S. Marti
•818-354-9089/phs@merlin.jpl.nasa.gov

High Tc Hot Electron.ppt

Submillimeter-wave cloud ice radiometry is uniquely able to determine the amount of ice present in cirrus clouds, characterize the median crystal size and constrain crystal shape.

“Obtaining quantitative global observations of cloud ice content is a high priority for the climate modeling community (WMO report, 1995):

- **Technique “baselined” for:**
  - **NASA ESE Post-2002 Cloud-Climate Feedback mission (EX-3).**
- **Applications:**
  - **Cloud - Climate Feedback Studies**
  - **Upper Tropospheric Chemistry Studies**
  - **Weather Prediction**



Isometric Drawing of the DC-8 Cloud Ice Radiometer being developed for the NASA IIP program. This diagram shows only the 643 GHz optical path.

Technology Development Needs:

- ***Terahertz Solid State Oscillators***
- ***Terahertz Detector Arrays***
- ***Terahertz Integrated Solid-state Receivers***

QWIP Focal Plane Array (FPA) Technology

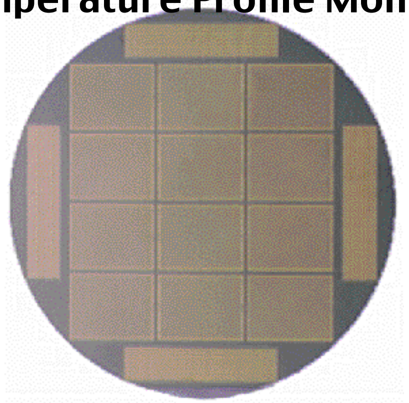
for Earth Science Applications

Potential Earth Science Applications

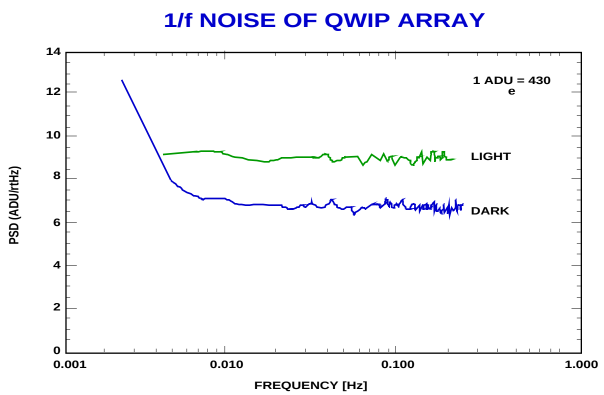
- Special Event Imaging
- Trace-gas Imaging
- Weather Monitoring
- Earth Resource Mapping
- Pollution Monitoring
- Cloud Characteristic Measurements
- Sea Surface Temperature Measurements
- Temperature Profile Monitoring

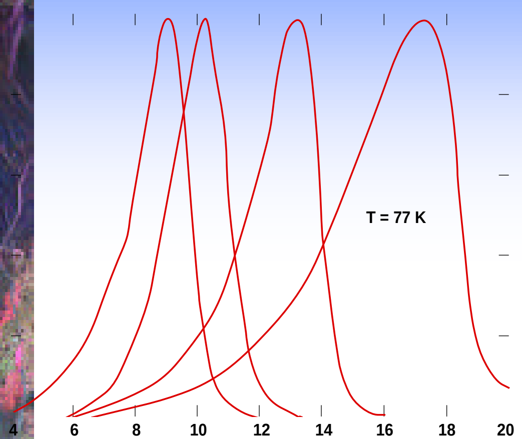
Advantages of QWIP FPAs in Comparison To Competing Technologi

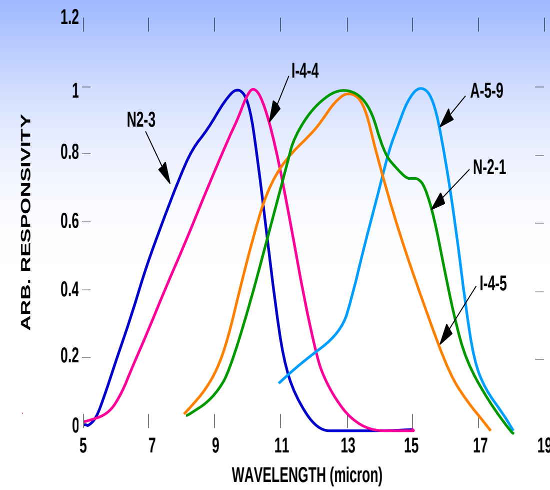
- Large Format FPAs
- Covers 3-20 μm Spectral Region
- Multi-Spectral
- Operability > 99.9%
- Uniformity > 98% (Uncorrected)
- Low 1/f noise
- Detectivity 1x1011 cm√Hz/W
- 150-60 K Operating Temperature
- High Radiation Hardness
- 20% Quantum Efficiency

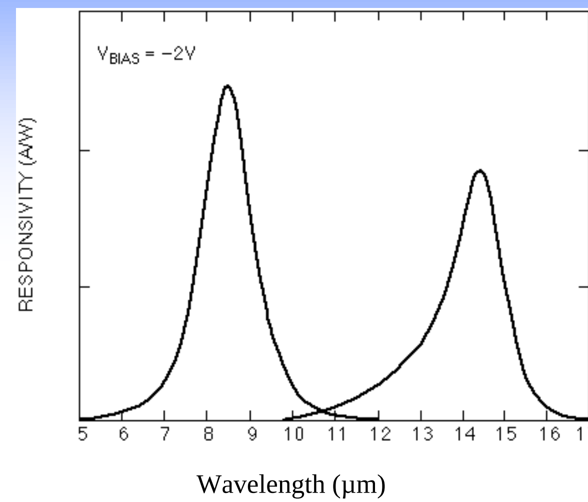


Twelve 640x512 QWIP FPAs on a 3' GaAs Wafer



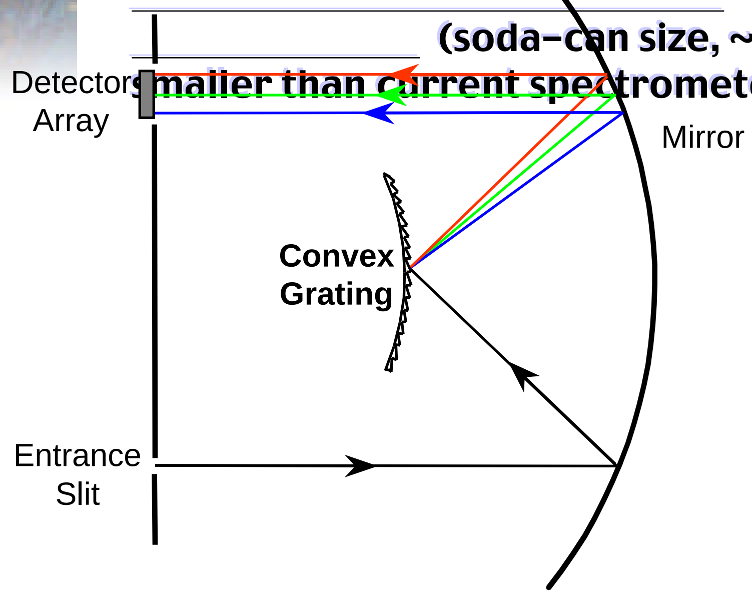




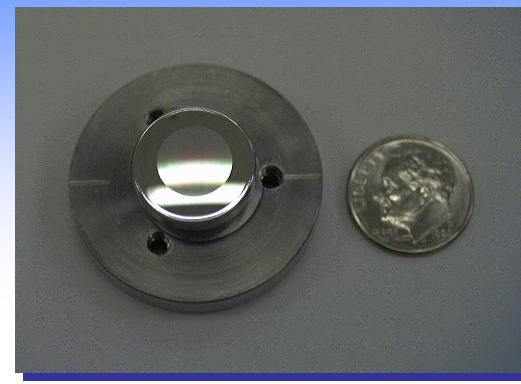


Broad-band, Narrow-band, and Multi-band Large Format QWIP FPAs cover 3–20 µm Spectral Region

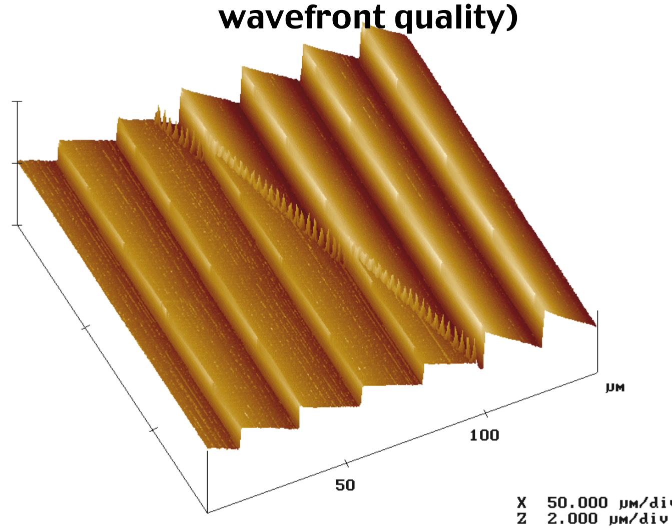
- ________________________ of imaging spectrometry:
  Mineral exploration, Hazardous waste monitoring, Crop/forest health, Urban monitoring, Land use changes, Fire/Wetlands monitoring
- For the first time, JPL has fabricated high-performance ________________________ ________ by using electron-beam lithography. These gratings ____________ ______________________________ ______________ (soda-can size, ~20 times smaller than current spectrometer volume)



____
"Offner" Imaging Spectrometer
(zero slit-image distortion, near diffraction limited)



Single-Blaze Grating on Aluminum Substrate for ______________________ (selected over diamond-ruled and holographic gratings based on measurements of efficiency, scattering, and wavefront quality)



Dual-Blaze Convex Grating – ______________ ______________ (75% peak, >20% for 0.4 – 2.5 microns) Provides flat and high signal to noise ratio.

Dan Wilson, Paul Maker, and Rich Muller

- Weather and environmental sensors are an important cross-cutting NASA technology.
- Existing technology is inadequate (due to size and/or measurement specs).

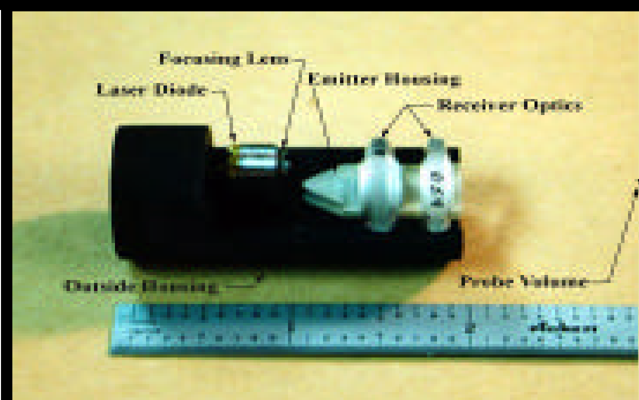
- Use advanced technology to combine accurate measurement techniques with small size.
- Instrument integration.

Dewpoint Microhygrometer

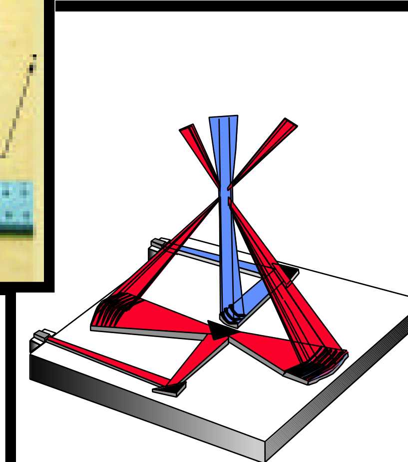
- Develop unique microsensors for accurate, low-power instruments.
- Flight validation of sensor technology.
- Demonstrate technology for new meteorological system – the Micro Weather Station

Reference Radiosonde

Sponsored by NASA ESE, SSE, and HEDS



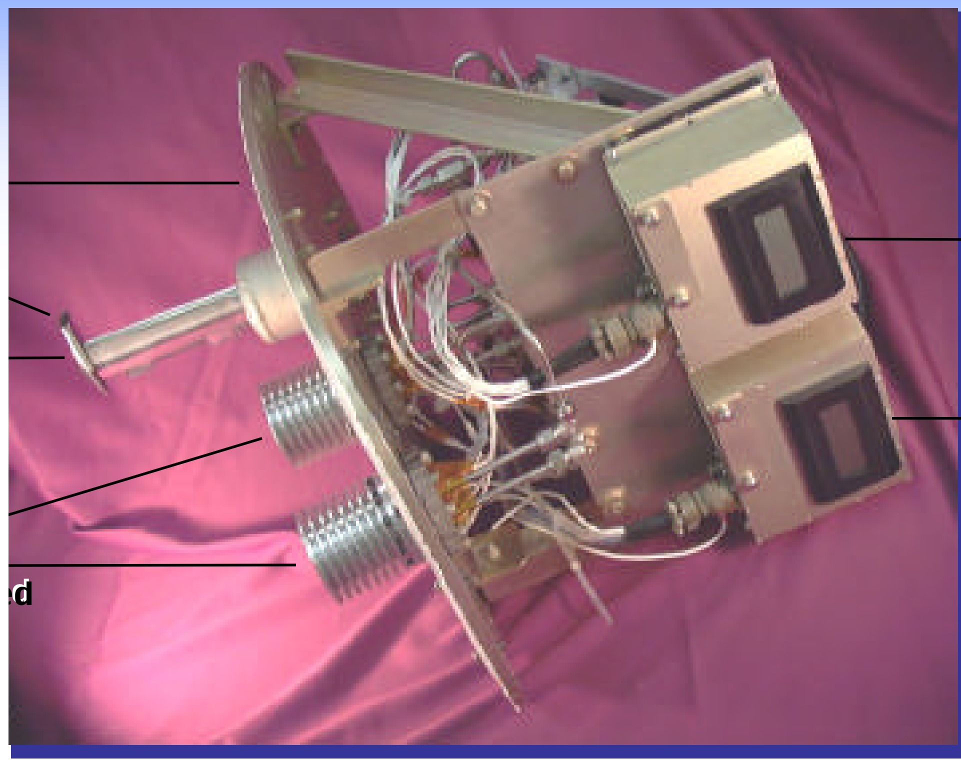
Miniature Laser Doppler Anemometer



Micro-optical wind and dust sensors

- atmospheric profiles and ground validation (ESE).
- meteorology sensors for planetary atmospheres (SSE).
- Advanced environmental monitoring on space station, RLVs (HEDS).

Third Convection and Moisture Experiment (CAMEX-3)



Active Sensing

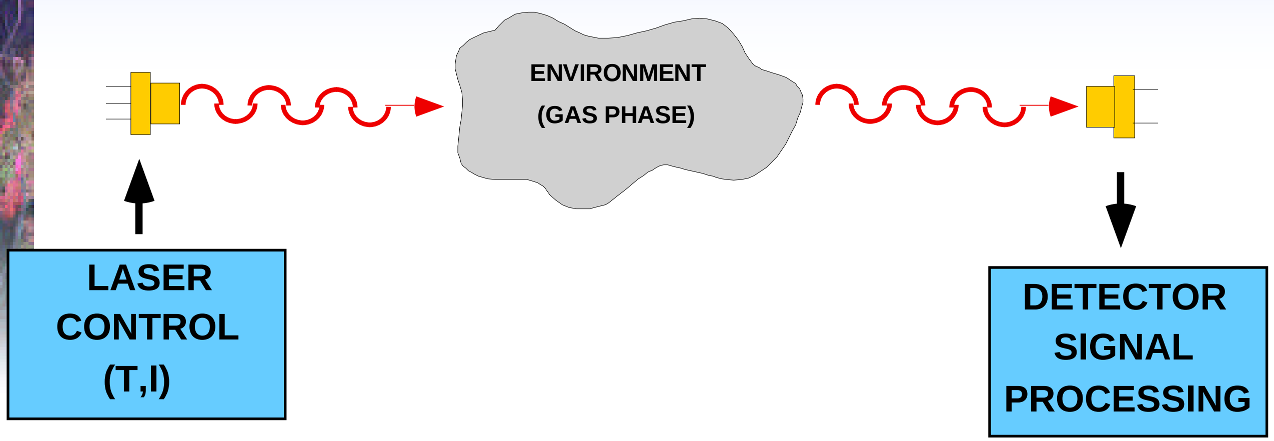
New Generation Diode Laser Sensors for In Situ Earth and Space Applications

High-Resolution Tunable Diode Laser Absorption Spectroscop

-
  - High Altitude aircraft and balloon in-situ measurements for atmospheric research
  - Pollution studies and hazardous gas monitoring
  - Industrial process and control and hazard warning systems
-
  - Atmospheric trace gas measurements (Mars '98, aerobots)
  - Evolved gas analysis (Mars'98, New Millennium Microprobe)
  - Advanced Life Support Systems/Environmental monitoring
- : NASA Code Y, Code S, JPL DR&DF (3 $M/yr)
-
  - JPL (R. May, C. Webster, S. Forouhar, P. Maker, S. Keo)
  - UCLA (D. Paige, MVACS P.I.)
  - Univ. N. Carolina (S. Woodward)
  - Lucent Technologies
  - NRL
  - Hughes
  - JSC

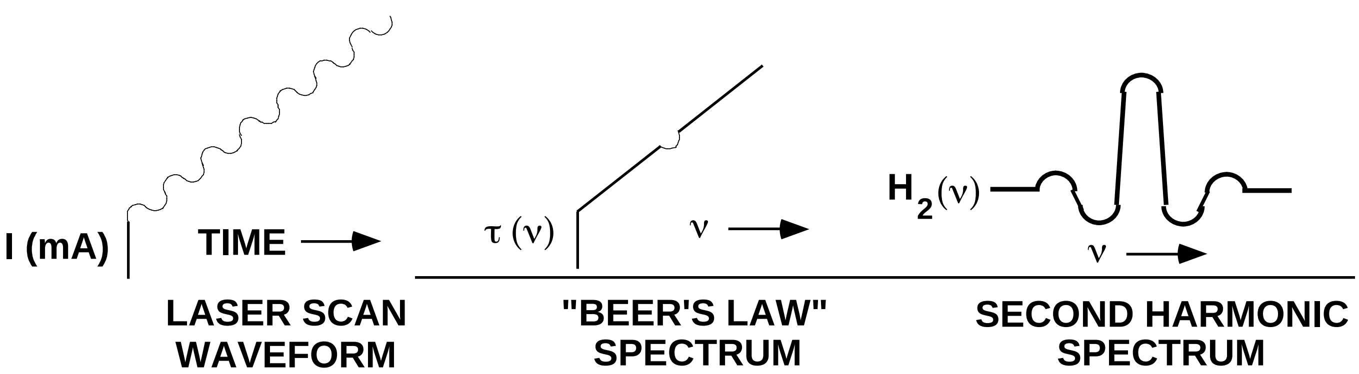
Absorption Spectroscopy Fundamentals

TUNABLE DIODE LASER ABSORPTION SPECTROSCOPY



- NON-INVASIVE
- DIRECT
- SIMPLE

SECOND HARMONIC DETECTION FOR HIGHER SENSITIVITY

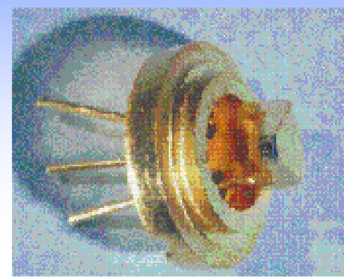


- ZERO-BASED
- MINIMUM 1/F
- SLOPE REMOVAL

JPL Atmospheric Laser Spectroscopy Instrument Development

Pb-Salt Lasers (Liquid He Cooled)	**(3-30 Micron)** **12 Flights (Balloon) 1983-92** **NO, NO_2, NHO_3, O3, CO_2, N_2O, CH_4, Isotopes**
Pb-Salt Laser (Liquid N_2)	**(3-30 Micron)** **>140 ER-2 Flights 1990-95** **CH_4, N_2O, CO, HC1, CO_2**
PH Salt Lasers (Liquid N_2)	**(3-30 Micron)** **N_2O, CH_4, CO (Perseus)** **CH_4, HC1, NO_2 (Balloon)**
InGaAs Lasers (Uncooled)	**1.3 Micron Single Channel (WB57, ER-2)** **H_2O, CO_2, NO, HC1, CO**
InGaAs Lasers (Uncooled)	**First Space Qualified System** **1.37 µm ($H_2{}^{16}O$, ${}^{12}C^{16}O_2$)** **2.04 µm ($H_2{}^{16}O$, $H_2{}^{18}O$) HDO** **${}^{12}C^{16}O_2$, ${}^{13}C^{16}O_2$, ${}^{12}C^{16}O^{18}O$, ${}^{12}C^{16}O^{17}O$)**

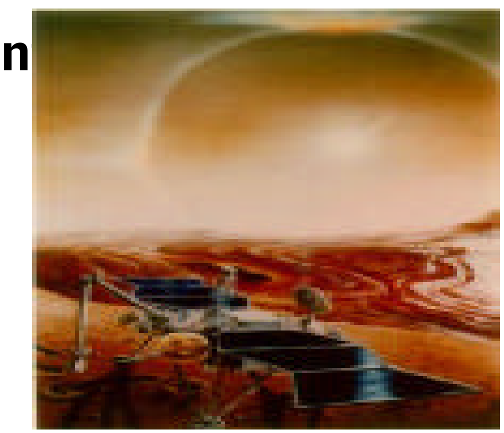
Photonics in Space – A Critical Technology



Typical Tunable Diode Laser

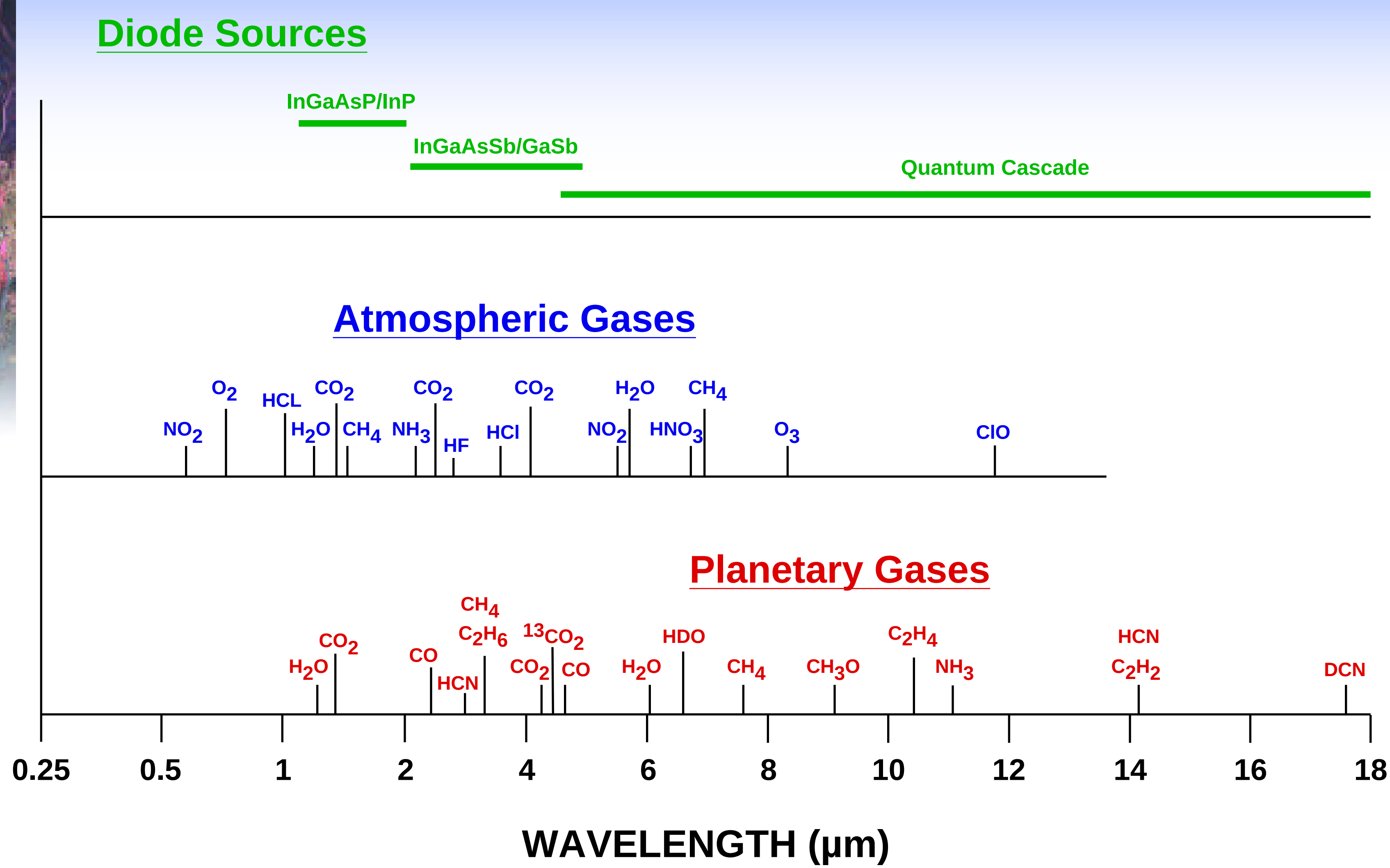
ER-2 water vapor instrument
(POLARIS mission)

DC-8 water vapor instrument
(CAMEX-3 mission)

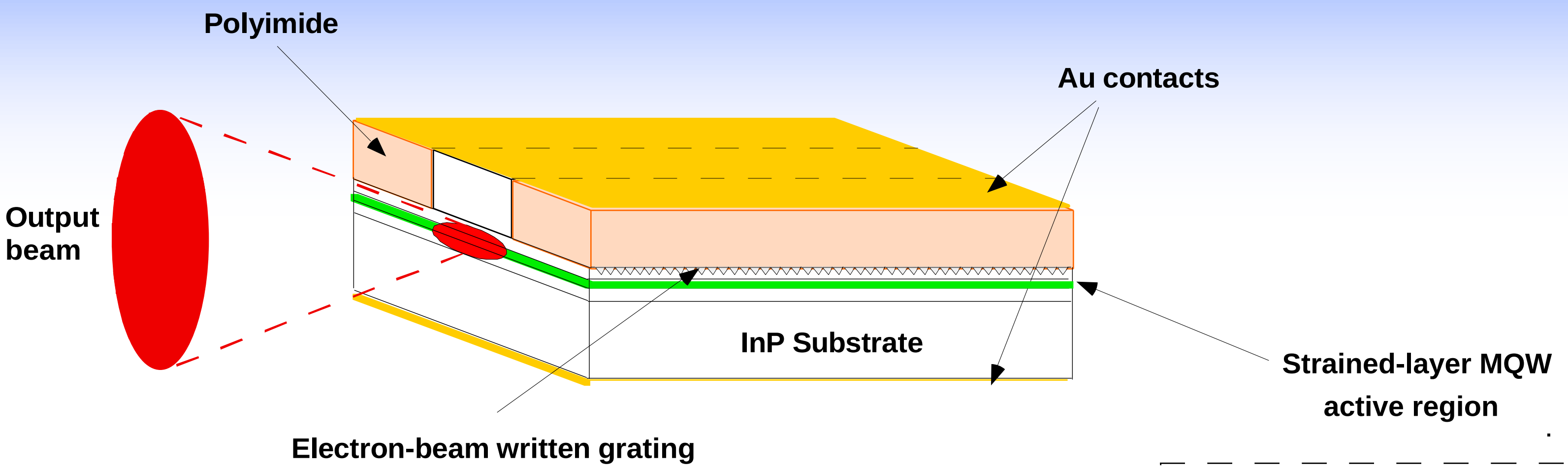


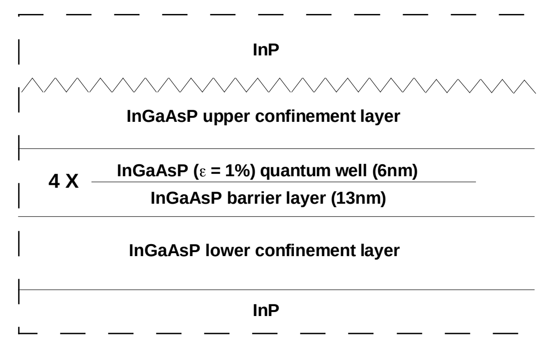
The Mars Volatiles and Climate Surveyor (MVACS) carries four TD

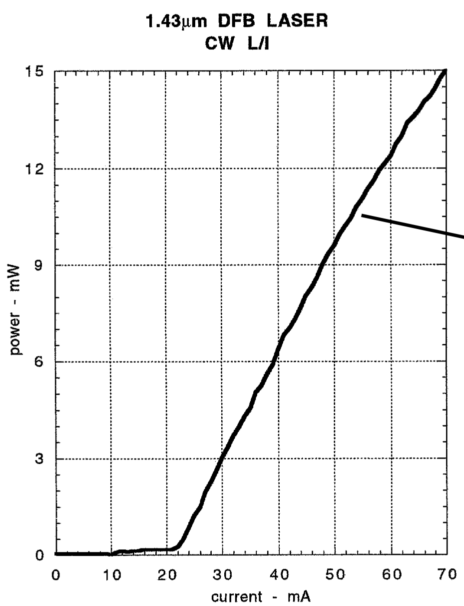
Absorption Lines for Relevant Laser Diodes

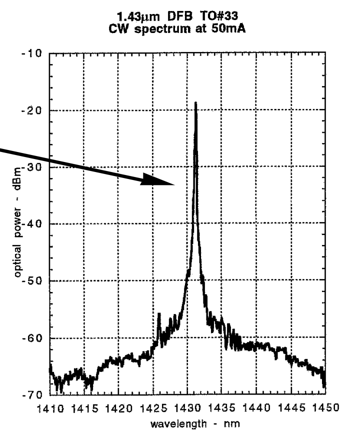


Distributed Feedback Ridge Laser









Facilities

Progress In Laser Development

- Laser Requirements for Spectroscopy
  - Single frequency
  - >0.5 mW output power
  - >1cm^{-1} tuning range
  - Stable against thermal cycling

- 1.37 µm (H2O) and 1.43 µm (CO2) DFB lasers fabricated by JPL and delivered for aircraft instruments

- 1.37 µm and 2.04 µm lasers fabricated by JPL and deliver for MVACS (Mars '98 Lander) and DS-2

- 2-5 µm lasers at ambient temperature under developm

- Quantum Cascade lasers in the 4-10 µm under developm

Miniaturization of Control Electronics and Progress in Software Development

- Electronics
  - ROM-based laser scan control (no analog generation)
  - Single-board laser control/signal processing circuit with <50 μW total power consumption
  - Hybrid version has 1” x 1” footprint, single 5V rail
- Software
  - Fully automated spectrometer control for continuous operation
  - “On-the-fly” data processing
  - <1s continuous response time (CPU dependent)
  - Currently working on automated calibration sequences

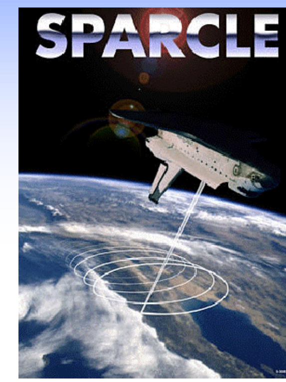
Commercial Applications

- Continuous Emission Monitoring (CEM)
  - Municipal waste disposal facilities (EPA regulated)
  - Hospital and hazardous waste disposal facilities
- Industrial Process Control
  - Contaminant monitoring and gas analysis
  - Hazard Warning Systems
- Natural Gas Pipeline Leak Monitoring (CH_4, 3.4 μm)
- Automotive Industry (e.g. CO in tailpipe, muffler)

Conclusion and Future Directions

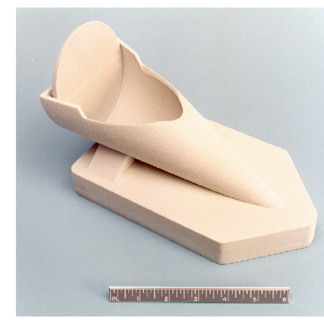
- Dramatic reduction in instrument mass, power, and volume achieved using new generation of lasers with no loss of sensitivity
- First TDL instrument selected and launched for space application
- New family of lasers under development which may revolutionize the spectroscopy science instruments

Lidar Technology Products for ESE



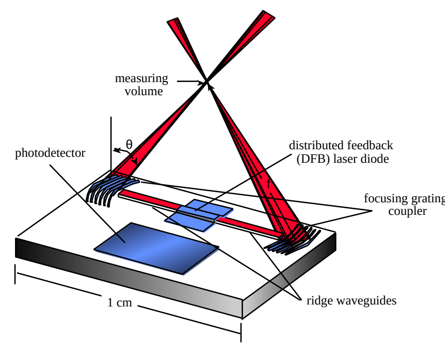
Tunable Reference Oscillator Technology

- Diode-pumped vibronic crystal laser; ±4 GHz single-frequency
  tunability demonstrated at 2.06 μm
- Technology transferred to industry for incorporation into NMP EO-2
  "SPARCLE" demonstration mission (MSFC)
- Novel compact semiconductor concept with improved agility and lifetime currently under development for long-duration operational missions



Miniature Coherent Wind Lidar Concept Development

- Short-range quasi- wind sensing with modulation-coded
  low-power transmitters
- Suitable for deployment on UAV platforms for point correlative
  validation of operational wind sensing instruments

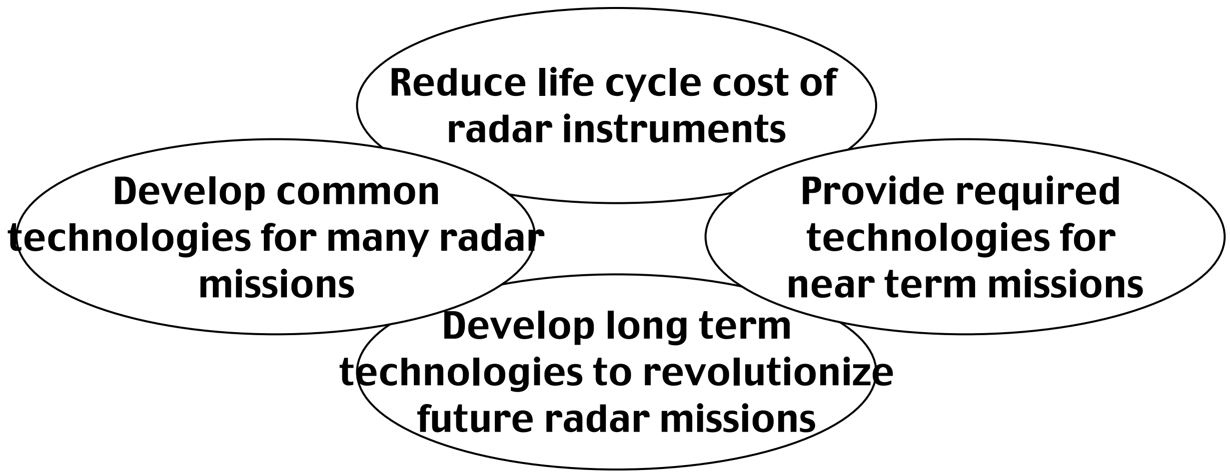


Long-Range "On Chip" Development

- Laser transmitters, focusing and pointing optics, and detector integrated on a single chip

Advanced Radar Technology Program (ARTP)

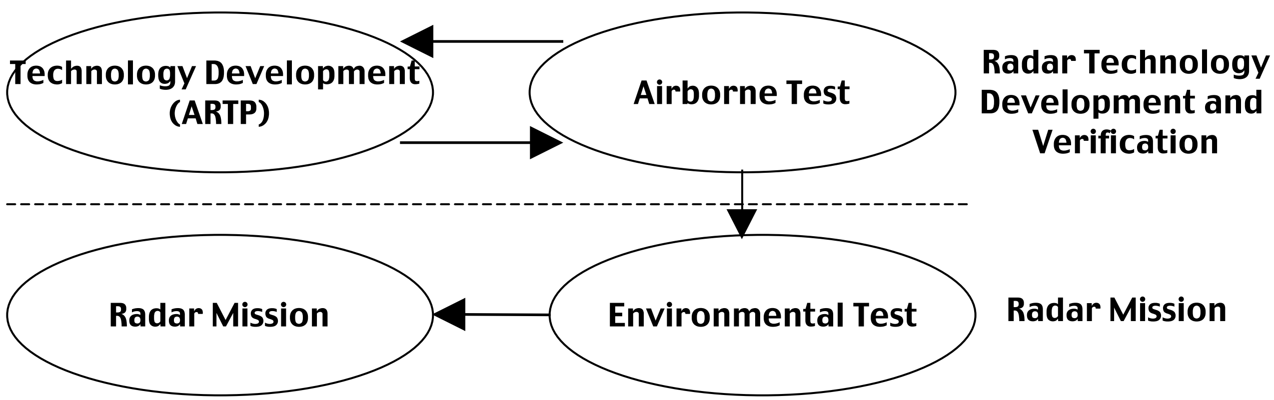
- JPL has been the world leader in developing science radar instruments for the past 25 years
- To enable frequent radar missions, the radar instrument costs must be reduced.
- ARTP is a focused radar technology program that will:



- Near-term missions: LightSAR, Planetary sounders (Mars and Europa), and Cloud Radar (CloudSat)
- Long-term missions: Beyond LightSAR

ARTP Approach

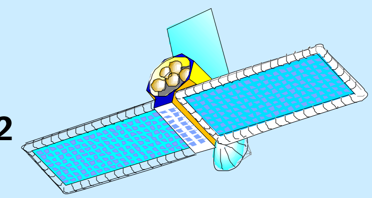
- Integrated system approach
- Seek and insert technology advances from all sources
- Develop innovative technologies to significantly reduce mass, volume, and power consumption with enhanced performance
- JPL-University-Industry partnership
- Systematic technology infusion process



Radar Miniaturization

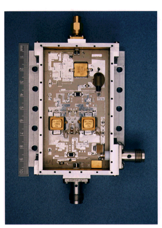
SIR-C 1994

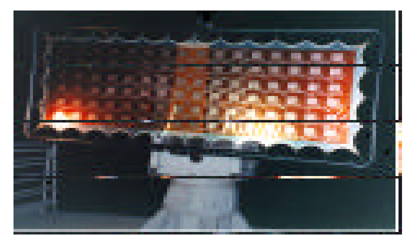
Visionary SAR 2005



Antenna mass: 23 kg/m^2	Antenna mass:1.6 kg/m2
Radar mass: 250 kg	Radar mass: 15 kg
Radar power: 650 W	Radar power: 100 W

Inflatable Antenna
MMIC
MEMS
ASIC





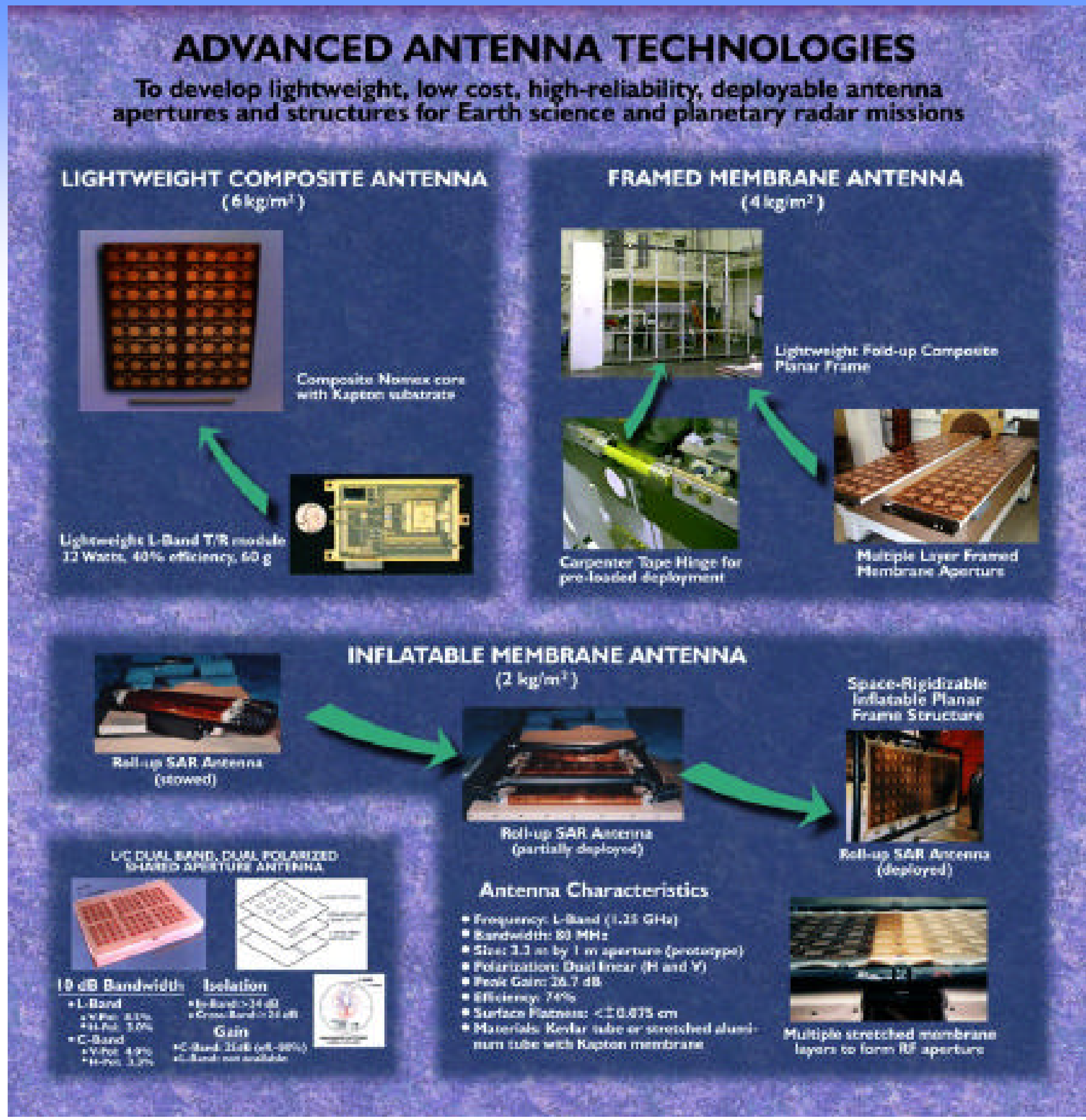
Advanced Radar Development Partnerships

Industry
- ILC-Dover
- L'Garde
- Composite Optics, Inc.
- CPI-Canada
- AME Space
- Lockheed Martin
- RDL
- ZAI Amelex

Academia
- U. Massachusetts
- U. Washington
- U. Colorado
- Stanford
- Caltech

Other NASA Centers
- Goddard
- Ames
- Glenn

Multi-Enterprise
- Code Y (Office of Earth Science)
- Code S (Office of Space Science)


ADVANCED ANTENNA TECHNOLOGIES
To develop lightweight, low cost, high-reliability, deployable antenna apertures and structures for Earth science and planetary radar missions
LIGHTWEIGHT COMPOSITE ANTENNA
(6 kg/m²)
Composite Nomex core with Kapton substrate
Lightweight L-Band T/R module
12 Watts, 40% efficiency, 60 g
FRAMED MEMBRANE ANTENNA
(4 kg/m²)
Lightweight Fold-up Composite Planar Frame
Carpenter Tape Hinge for pre-loaded deployment
Multiple Layer Framed Membrane Aperture
INFLATABLE MEMBRANE ANTENNA
(2 kg/m²)
Roll-up SAR Antenna
(stowed)
Roll-up SAR Antenna
(partially deployed)
Space-Rigidizable Inflatable Planar Frame Structure
Roll-up SAR Antenna
(deployed)
L/C DUAL BAND, DUAL POLARIZED SHARED APERTURE ANTENNA
10 dB Bandwidth
• L-Band
• C-Band
Isolation
Gain
Antenna Characteristics
• Frequency: L-Band (1.25 GHz)
• Bandwidth: 80 MHz
• Size: 3.3 m by 1 m aperture (prototype)
• Polarization: Dual linear (H and V)
• Peak Gain: 28.7 dB
• Efficiency: 74%
• Surface Flatness: <±0.075 cm
• Materials: Kevlar tube or stretched aluminum tube with Kapton membrane
Multiple stretched membrane layers to form RF aperture

ADVANCED RADAR ELECTRONICS & SYSTEMS

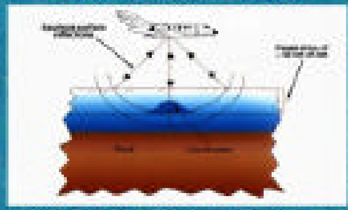
To develop lightweight, low cost, high-efficiency electronics and innovative new system architectures for Earth science and planetary radar missions

PLANETARY SOUNDER RADAR TECHNOLOGIES

Europa Orbiter Concept

- Clutter cancellation processing technique to reduce surface ambiguities
- Low frequency, ultra lightweight, deployable antenna
- Broadband, high efficiency, lightweight Class-E amplifier
- Low power, lightweight on-board processor
- Miniaturized, low power electronics
- Extreme environment components (high radiation and low temperature)

Airborne Sounder Testbed



Conduct field experiments in Greenland and Antarctica to demonstrate the design and technologies proposed for planetary sounders

HIGH EFFICIENCY CLASS-E AMPLIFIER

Class-E Amplifier

- 50 MHz amplifier with 30 Watts output power, 90% efficiency and 45 dB gain
- Acts as T/R switch for further mass reduction

MEMS INDUCTORS

- Small size (100 mm^2 chip), low loss, voltage tuneable inductance
- Applications in:
  - amplifier miniaturization
  - tuning for high efficiency Power Amplifiers
  - antenna matching network

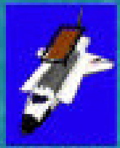
MEMS Inductor

ADVANCED L-BAND SAR ELECTRONICS

- Wideband NCO-based digital chirp generator
- 200 Watt L-band solid state power amplifier
- MMIC low noise, high dynamic range receiver
- High speed digital electronics

ADVANCED SYSTEMS & MISSION CONCEPTS

- Space demonstration of Inflatable SAR to verify mechanical and RF performance of inflatable membrane antenna and advanced SAR electronics
- Ground demonstration of an accurate multiple-polarization Ku-band scatterometer system for snow backscatter measurements
- System demonstration of a miniature ground penetrating radar for Mars rover applications



Inflatable SAR Space Demo

94 GHz SPACEBORNE EXTENDED INTERACTION KLYSTRON AMPLIFIER

- 1.5 KWatts, 30% efficiency
- High cathode current density
- Depressed collector
- Conduction cooled
- Long lifetime reservoir cathode
- Ruggedized packaging

CLOUDSAT – A Success Story

For CSMT – ARTP Program

- 1993– 1996 CSMT Sensor Technology Program jointly funded technology development of the Airborne Cloud Radar with NASA Code Y Atmospheric Dynamics & Remote Sensing Branch (R. Kakar)

  Collaboration: University of Mass
  Colorado State University
  JPL Lead Fuk Li

- 1996 Continued Joint Development of the Cloud Radar with Code Y Cloud & Radiation Program (Bob Curran)

- April 1999 NASA Awarded CLOUDSAT Mission to JPL with Colorado State University as PI ($110 M)

  Collaborator: Canadian Space Agency, USAF
  (~$25 Commitment)

ARTP Contribution to CloudSat

- 95 GHz high power transmitter is the most critical technology challenge to enable spaceborne cloud profiling radar

- Feasibility study of using EIK (Extended Interaction Klystron) for a spaceborne cloud profiling radar (1993)
- Develop enabling EIK technologies with CPI-Canada
  - Conduction cooling
  - Use of depressed collector for higher efficiency
  - Innovative packaging for space environment (vibration, shock, thermal)
  - Innovative application of reservoir cathode for longer lifetime operation under space environment
- Technology Validation
  - Vibration Engineering Model delivery in March 1999
  - Thermal Vacuum Engineering Model delivery in December 1999.

- F = 95 GHz
- Po = 1.5 kW min
- Duty = 3 %
- Efficiency = 30%
- Conduction cooled

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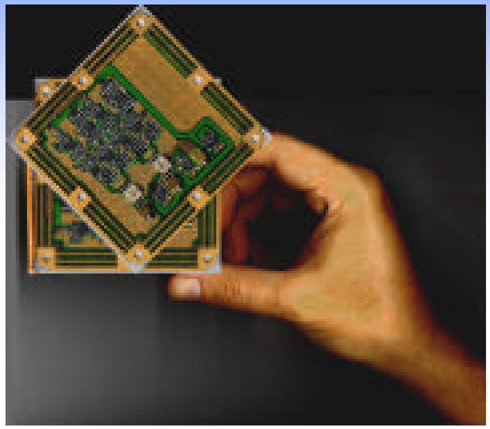
Micro Systems

JPL Is Developing Common Technology Needed For Micro Systems:

- Microavionics-SOAC
- Micro-Inertial Reference System
- Integrated Sensors
- MEMS micropropulsion
- Short range and long range miniaturized communication system
- Miniaturized, integrated power sources
- Distributed power system

"GPS on a Chip"



Co-funded by NASA Codes S & Y ; Collaboration with GSFC & Stanford University

Goal is to produce prototype HW/SW which meets demanding science requirements with low-power, low-cost

For the "basic" space-based GPS applications, GPS-chip is smaller & more accurate by factor of four

No suppliers for some applications: Atmosphere, attitude autonomy. GPS-chip enables a single board spacecraft, providing the following functions:

Real-time P, V, T & attitude Command Uplink (S-band) Flight Computer Science Observation Scheduling Science Measurements Data Storage	Attitude Actuators RF Down-link Power System

"GPS on a Chip"

Customers

Missions	Special Function
Grace (Gravity & Atmospheric)	Simultaneously provide 10 cm orbit, 3 mm relative positioning 1 micron non-GPS microwave ranging and 10 arc-second star-imaging for attitude
SAC-C (Magnetics, Imaging & Atmosphere)	Timetag and locate magnetometer data while producing atmospheric profiles
CHAMP (Magnetics, Gravity & Atmosphere)	Update spacecraft ephemeris, provide 10 cm orbit, and atmospheric profiles
JASON-1 (Ocean Altimetry)	Provide "phenomenal" 1 cm orbits with high reliability

Micro Inertial Reference System

- High performance:

  "match-frequency"

- Low Cost:

- Low Power:

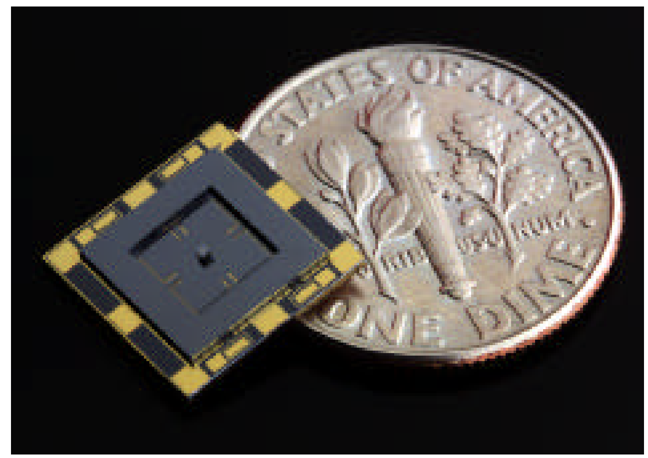
- Ultra-compact:

- Digital compatibility:

- Multi-sensor integration:

- Reliability:

- Navigation system on System-on-a-chip design approach.



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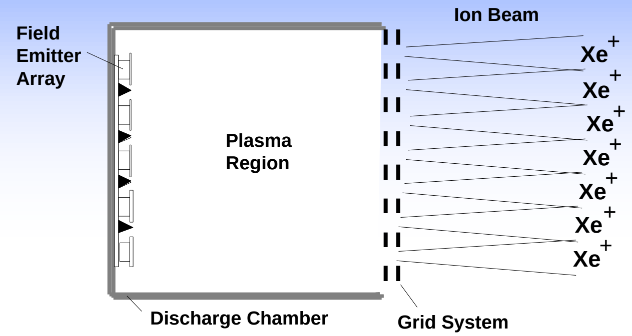
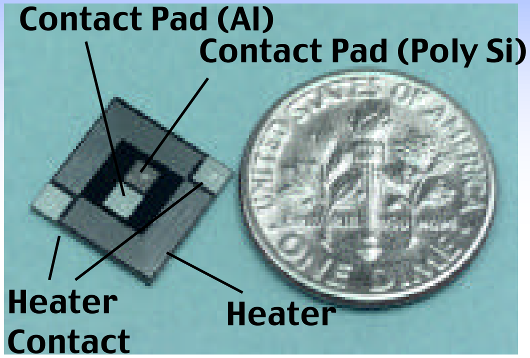
Micro Propulsion Engine

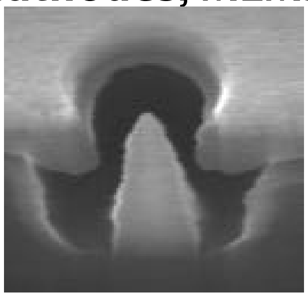


MEMS-Hybrid Micro-Ion Engine Concept

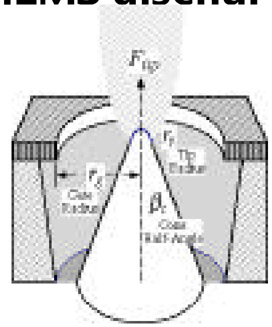


Test Chip to measure Electric Breakdown Characteristics of Silicon Oxide for Use in MEMS Grids

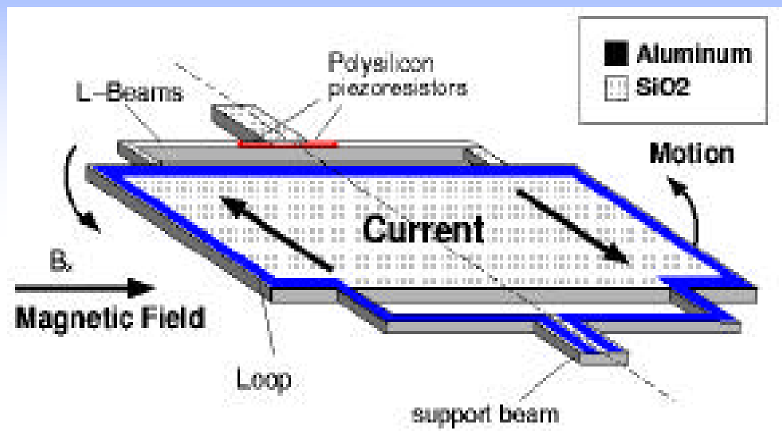
- Target 1-3 cm dia. chamber design
- Feasibility Issues: Discharge generation in small discharge chambers, cathodes, grids
- Pursue MEMS-hybrid thruster concept: Non-MEMS discharge chamber body, MEMS cold cathodes, MEMS grids

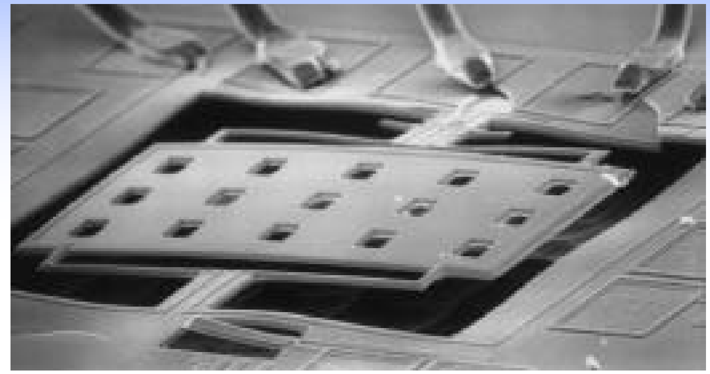


Micro-Fabricated Field Emitter Tip (C.Spindt/SRI)



Single tip and gate electrode configuration (Kevin Jensen at NRL)

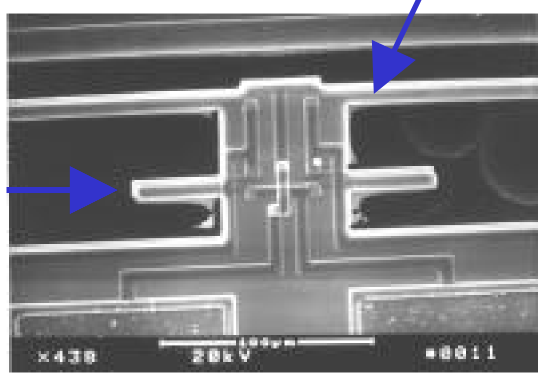




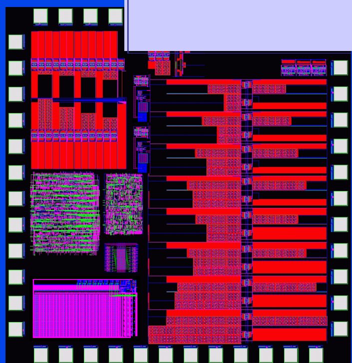
- One post-processing step following CMOS MOSIS run
- Vibratory structure enhances Lorentz force signal by Q
- Piezoresistive transduction with Wheatstone bridge reduces thermal noise response

Active resistors in beam

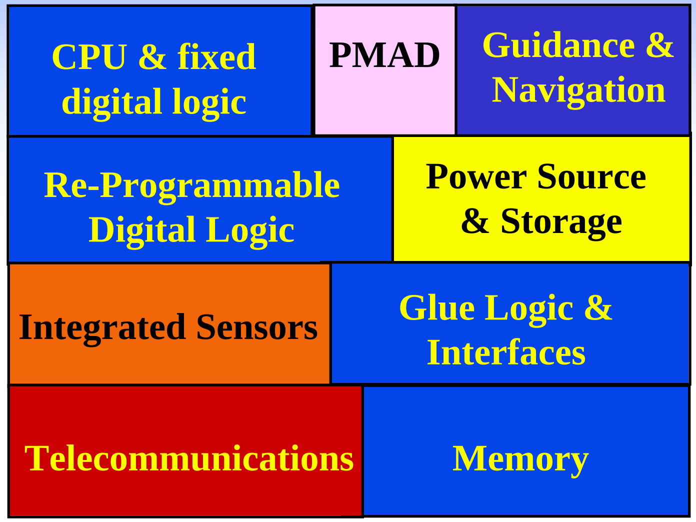
Passive resistor
s

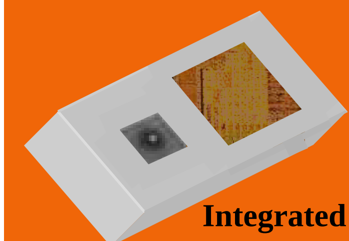


System on a Chip (SOAC)–Technology

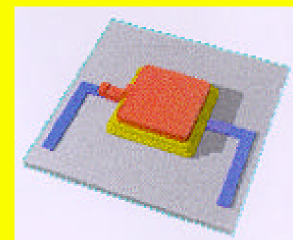


Design, Integration, Fabrication and Test



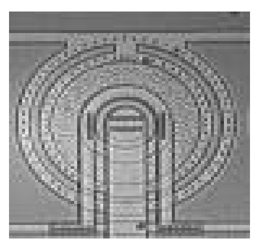


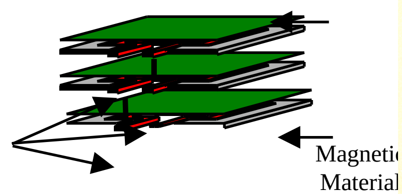
Integrated Sensors



On-Chip Power Source

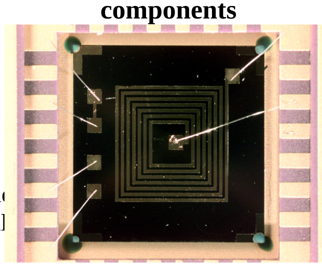
PMAD





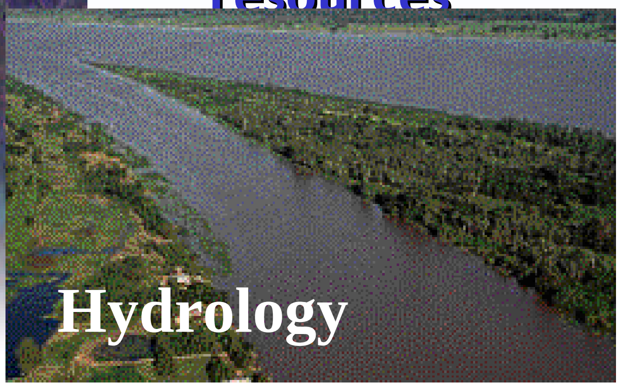
Thin film microtransformers

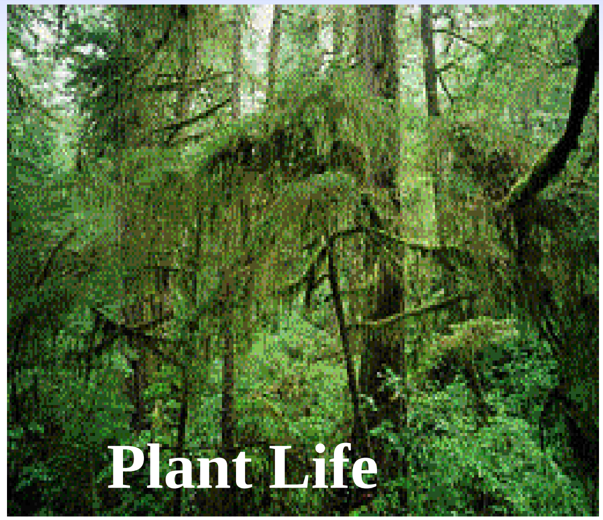
Embedded passive components

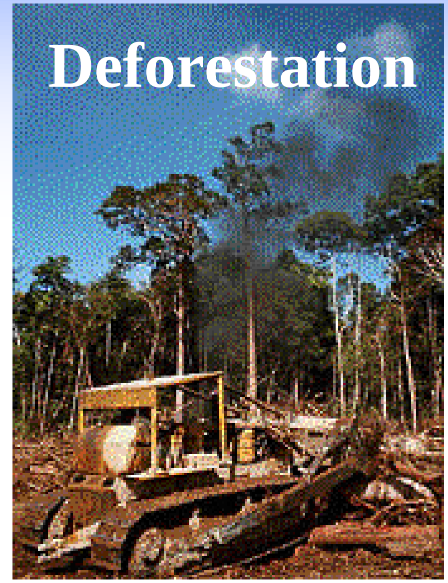


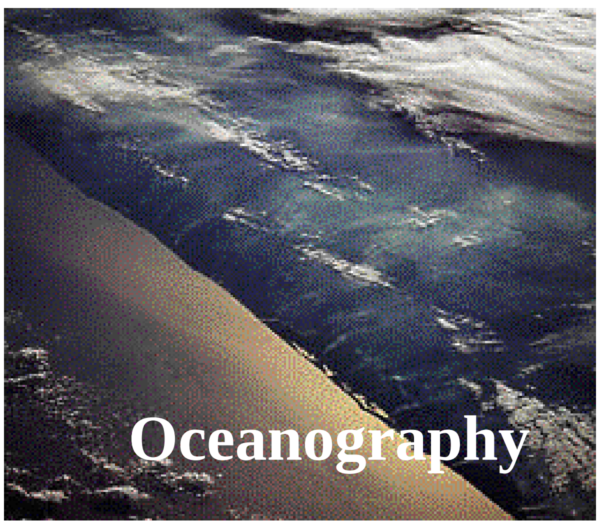
Distributed Microsystems for Earth Science

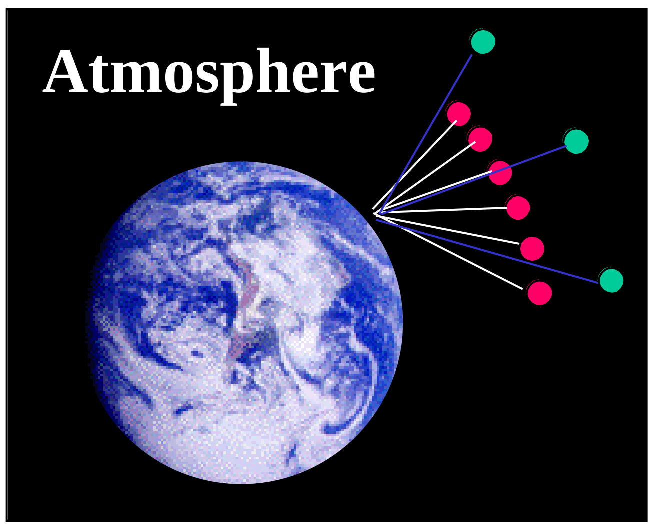
- surface
- atmosphere
- biomass
- resources

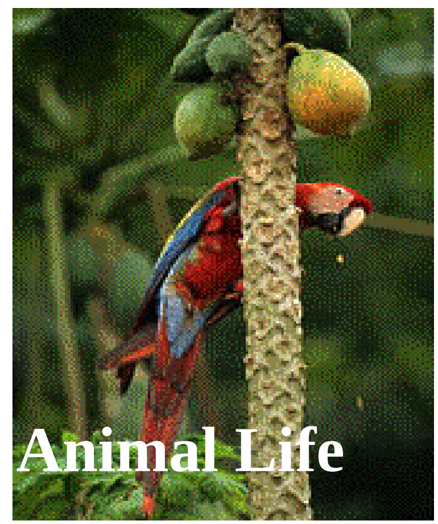




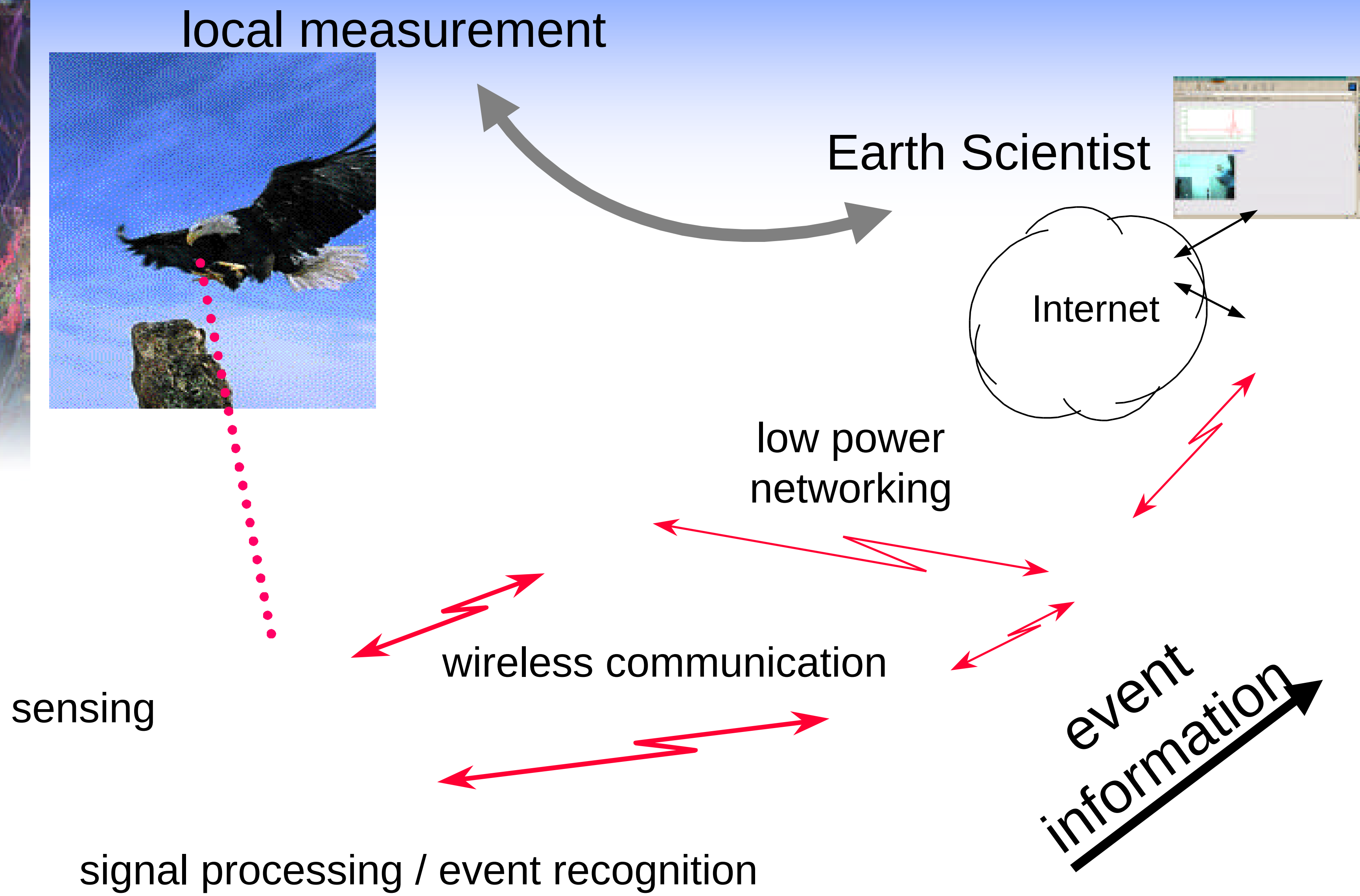








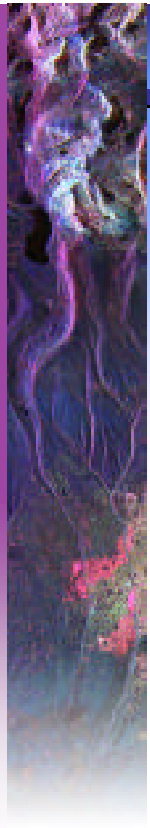
Wireless Integrated Network Sensors (WINS)



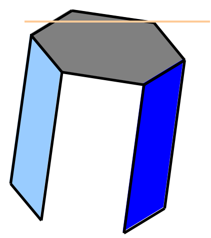
W. J. Kaiser, UCLA/JPL

Classifications of Future Miniaturized Spacecraft

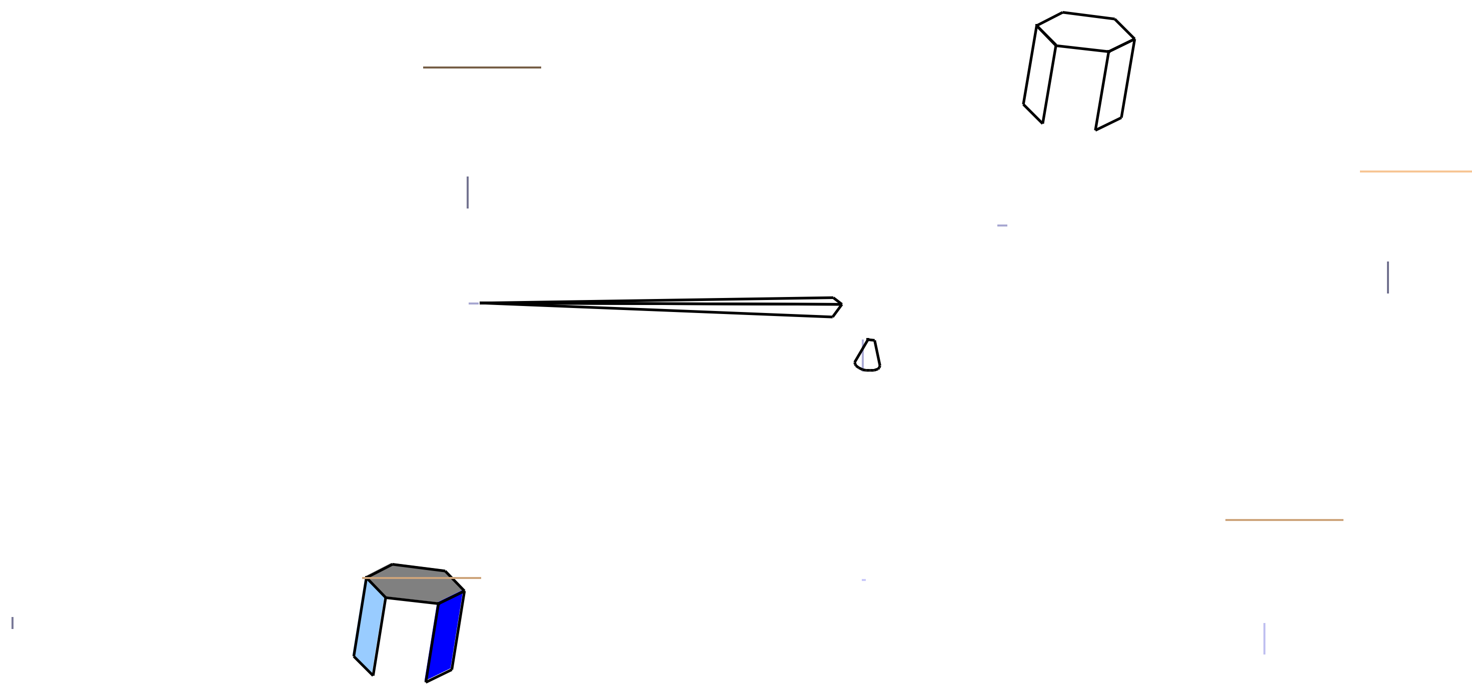
Mass (kg)	*Size (m)*	*Power (W)*	*Comments*
10–20	0.3–0.5	20	Conventional components, hybrid integration, with some MEMS devices.
1–5	~0.1	1	Mainly MEMS components, high levels of integration micro-propulsion a must.
<0.1	<0.03	<0.1	All MEMS, near total integration,



1-kg Micro-spacecraft

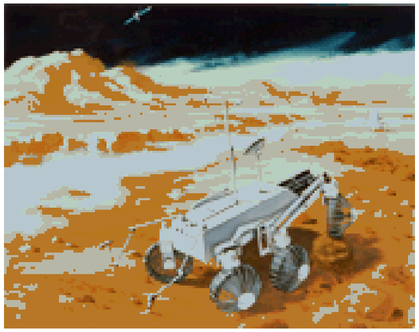
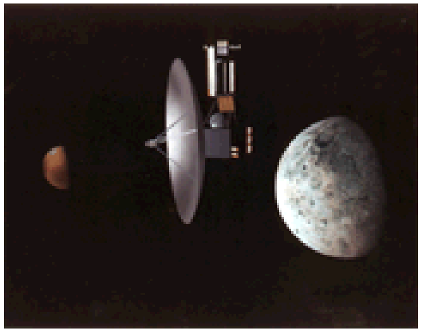
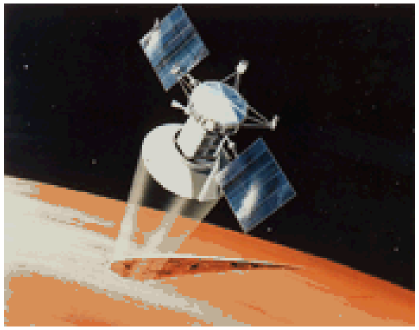


Future: Cooperative Fleet of MEMS-Enabled Spacecraft



Advanced Computing

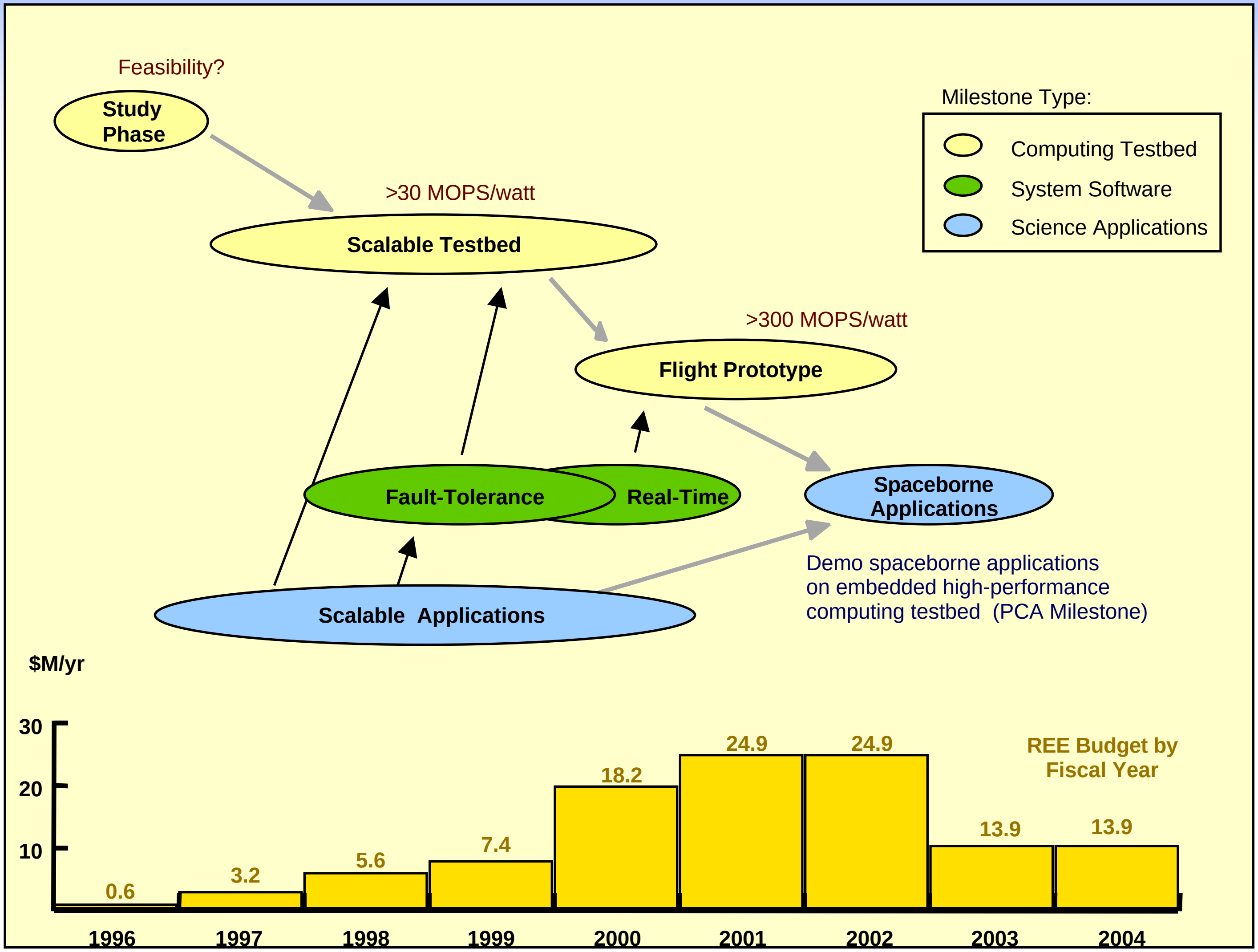
Remote Exploration and Experimentation Project

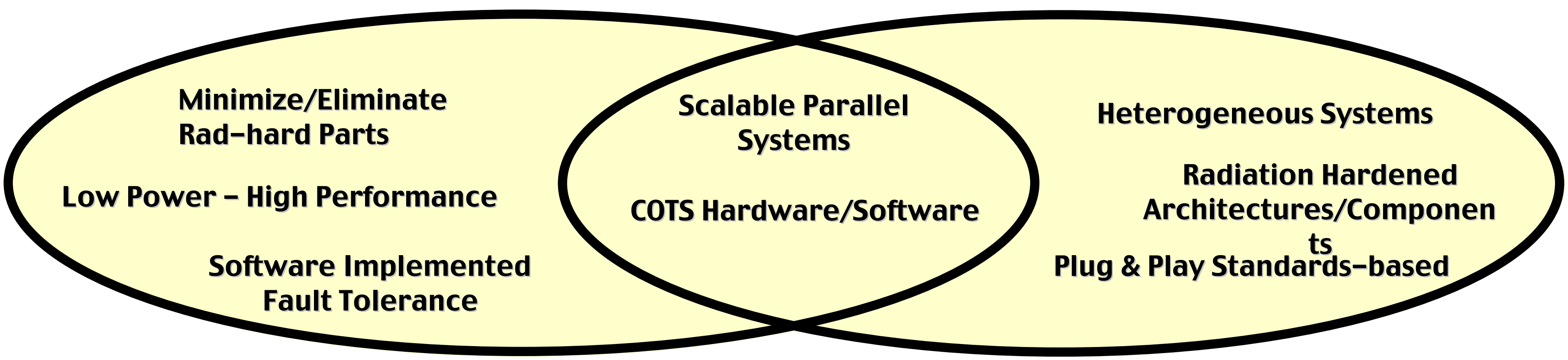
REE Objectives

- Demonstrate power efficiencies of 300 –1000 MOPS per watt in an architecture that can be scaled up to 100 watts, depending on mission needs.
- Demonstrate new spaceborne applications on embedded high-performance computing testbeds which return analysis results to the earth in addition to raw data.
- Develop fault-tolerant system software that will permit reliable operation for 10 years and more using commercially available or derived components.
- Enable ultra-low power onboard computer systems which will help open the entire Solar System to exploration

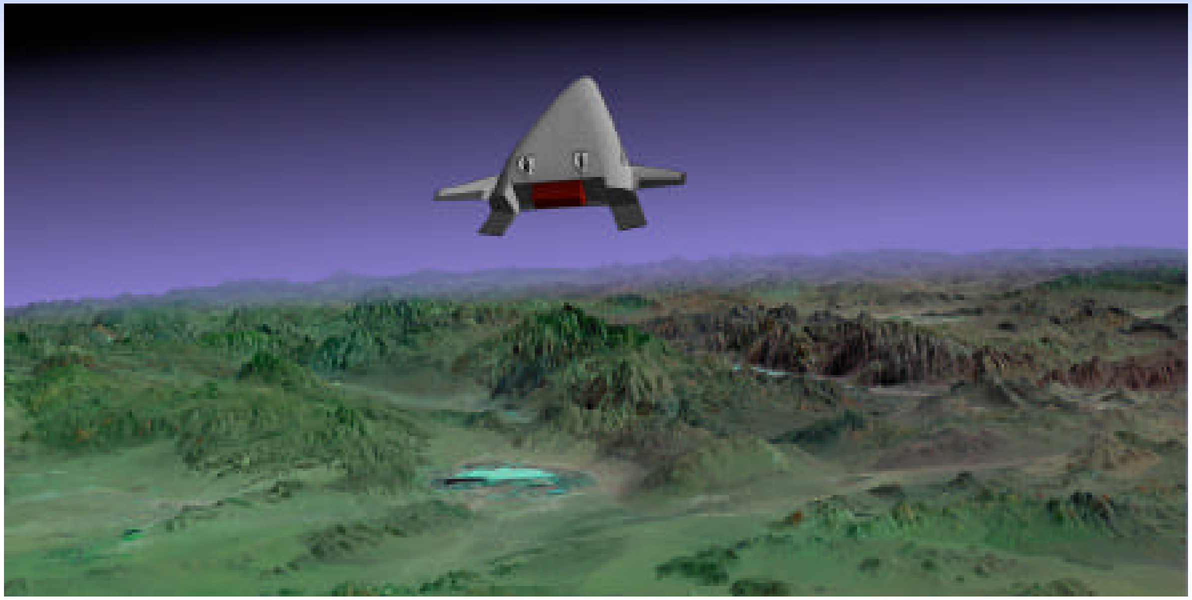
Project Objectives



Current Partnerships

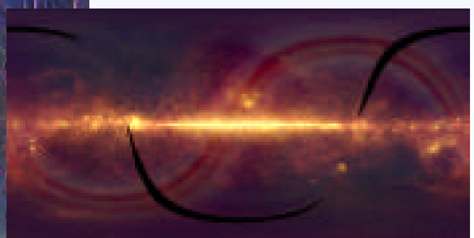


Digital Earth



- VP Gore's vision of a 3m Digital Earth will demand petabytes of data online.
- JPL's contribution to the NASA DE program builds large dataset storage and display technology leading to this vision.

High Performance Information Technology Integratio

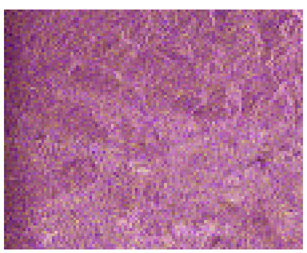


All-Sky surveys are 10 TB each

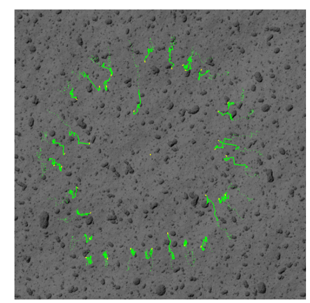
In Collaboration With

This digital animation plays at 225 mbyte/s

- Link the National Transparent Optical Network, NTON, to several key High Performance Information Technology (HPIT) assets at JPL and ARC,
- Add selected key elements of missing infrastructure technology to these networks and,



SAR interferometry for crustal deformation monitoring



Virtual rovers navigating a synthetic terrain

Intelligent Synthesis Environment

- Advanced technology development initiative started by Dan Goldin to improve NASA's technology base and to provide industry and academia with the impetus for pursuing technology research for space applications.

- Each of the Enterprises and each of the centers are represented on the ISE Element teams.
  - Developing and integrating simulation techniques for mission and system design, cost and risk management, and technology and design validation.
  - Developing collaborative engineering environment and the training needed to make the best use of the technologies developed.

JPL Intelligent Synthesis Environment Application Development

- As part of its ISE role, JPL, in collaboration with the other NASA Centers, will be developing and validating:
  - Improved and extended real-time collaborative engineering capabilities.
    - Video and teleconferencing using distributed modeling and simulation capabilities.
  - Simulation techniques and tools for design and validation throughout the mission life-cycle.
    - Virtual environments for mission planning, system design, operations simulation throughout the life of the mission
    - Cost and risk management techniques and tools.
      - Risk assessment through what-if scenarios in a virtual environment
  - Cultural change and training techniques and processes.
    - Training in the use of the new tools, techniques and processes

Cross Enterprise benefits

- ISE capabilities will reduce life-cycle cost and risk.
  - Collaboration techniques will allow real-time interaction between mission partners on planning and design throughout the mission life-cycle.
  - In addition, the collaboration process will encourage increased interaction without the cost and schedule impacts caused by travel.
  - Simulation of design and plans will reduce cost in development and risk in deployment through validation of designs and scenarios.
- Modeling and Simulation tools and techniques developed for Deep Space Enterprise are applicable to Earth Observing Enterprise
  - Capabilities are extensible/adaptable to the concepts that differ between Deep Space and Earth Observing missions.

Microdevices Laboratory (MDL)

Microinstruments and MEMS devices

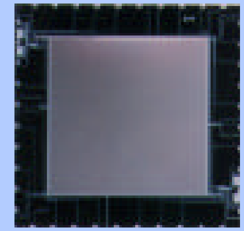
- Surface/Bulk micromachining
- Invention of tunnel transducer technology
- Microinstruments including
  - m-seismometer
  - microgyroscope
  - m-weather station
  - m-accelerometer


The Microdevices Laboratory (MDL) is a state of the art facility focused on creating the building blocks enabling NASA's vision of smaller, faster, cheaper spacecraft

<u>MDL Facilities include:</u> Class 10 cleanroom; E-beam and optical lithography; MBE, MOCVD, LPCVD growth systems; RIE systems; and full processing and characterization capabilities

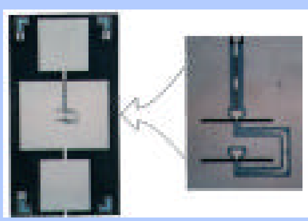
For more information: http://mishkin.jpl.nasa.gov

IR Focal Plane Array UV & X-Ray CCD



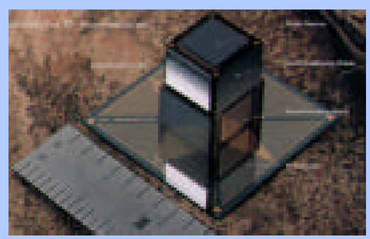
- (QWIP) Quantum well IR photodetector arrays based on GaAs/AlGaAs MBE structures
- Enhanced UV / X-ray CCDs via MBE d-doping
- GaN growth & devices

Superconducting Devices



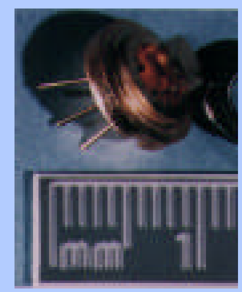
- Mixer arrays for sub-mm astronomy and atmospheric chemistry - SIS and hot electron bolometer mixers
- FIR bolometers
- Lo-Tc and hi-Tc materials

Neural Network Processors



- Autonomous control
- High speed processing
- Pattern recognition

Semiconductor Lasers



- Narrow linewidth, 300K tunable diode lasers
- InGaAsP lasers to 2.0 mm for spectroscopy
- Laser arrays for high rate comm (10's Gb/sec)